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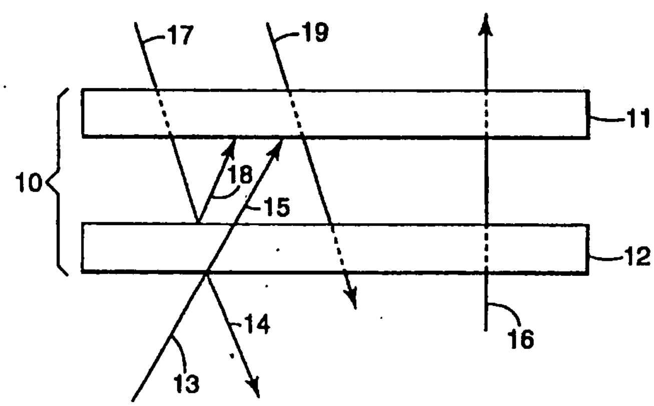


(57) Abstract

A reflective polarizer and a dichroic polarizer are combined to provide an improved optical polarizer. The dichroic and reflective polarizers are typically in close proximity to each other, and are preferably bonded together to eliminate the air gap between the polarizers. The combination of the two polarizers provides a high reflectivity of one polarization and high transmission for the perpendicular polarization from the reflective polarizer side of the combined polarizer, and high absorption and transmission for light of orthogonal polarization from the dichroic polarizer side. The combination also reduces iridescence as seen in transmission and when viewed in reflection from the dichroic polarizer side. The increased extinction ratio and low reflectivity of the optical polarizer allows use of a lower extinction ratio dichroic polarizer in applications requiring a given extinction ratio and high transmission.

OPTICAL POLARIZER

Technical Field

The invention is an improved optical polarizer.

Background

Optical polarizing film is widely used for glare reducing sunglasses, increasing optical contrast, and in Liquid Crystal Displays (LCD). The most commonly used type of polarizer used in these applications is a dichroic polarizer. Dichroic polarizers are made by incorporating a dye into a polymer sheet that is stretched in one direction. Dichroic polarizers can also be made by uniaxially stretching a semicrystalline polymer such as polyvinyl alcohol, then staining the polymer with an iodine complex or dichroic dye, or by coating a polymer with an oriented dichroic dye. These polarizers typically have an extinction ratio (the ratio of transmission of light polarized perpendicular to the stretch direction to the polarization parallel to the stretch direction) of over 500:1. Dichroic polarizers normally has some absorption of light polarized in the high transmission orientation. Losses in this orientation are typically 10-20%.

Commercial polarizers typically use polyvinyl alcohol as the polymer matrix for the dye, however other polymers can be used. US Patent 4,756,953 describes the use of polyethylene naphthalate as the polymer matrix.

Low profile, sheet form reflective polarizers are available that reflect one polarization of light and transmit the other. These polarizers tend to be more efficient in transmitting light of the high transmission polarization. This is due to the use of a non-absorbing dielectric stack for polarizing light. These polarizers tend to have equal reflectivity for light irradiating the sheet from either side. These types of polarizers also tend to have some defects, such as leakage of light

Brief Description of the Drawings

The various objects, features and advantages of the present optical polarizer shall be better understood upon reading and understanding the following detailed description and accompanying drawings in which:

FIGURE 1 shows the present optical polarizer, including a reflective polarizer and a dichroic polarizer placed proximate thereto;

FIGURE 2 shows a preferred multilayer reflective polarizer having a dichroic polarizer bonded thereto;

FIGURE 3 shows one embodiment of a display incorporating a reflective polarizer and dichroic polarizer;

FIGURE 4 shows another emboidment of a display incorporating a reflective polarizer and dichroic polarizer;

FIGURE 5 shows another embodiment of a display incorporating two combined reflective polarizers and dichroic polarizers;

FIGURE 6 shows a liquid crystal display incorporating a reflective polarizer and a dichroic polarizer;

Figure 7 shows a two layer stack of films forming a single interface.

Figures 8 and 9 show reflectivity versus angle curves for a uniaxial birefringent system in a medium of index 1.60.

Figure 10 shows reflectivity versus angle curves for a uniaxial birefringent system in a medium of index 1.0.

Figures 11, 12 and 13 show various relationships between in-plane indices and z-index for a uniaxial birefringent system.

Figure 14 shows off axis reflectivity versus wavelength for two different uniaxial birefringent systems.

Figure 15 shows the effect of introducing a y-index difference in a biaxial birefringent film.

Figure 16 shows the effect of introducing a z-index difference in a biaxial birefringent film.

Figure 17 shows a contour plot summarizing the information from Figures 10 and 11;

The preferred and illustrative reflective polarizer body 12 shown in FIG. 2 is made of alternating layers (ABABA...) of two different polymeric materials. These are referred to as material "(A)" and material "(B)" throughout the drawings and description. The two materials are extruded together and the resulting multiple layer (ABABA...) material is stretched (5:1) along one axis (X) and is not stretched appreciably (1:1) along the other axis (Y). The X axis is referred to as the "stretched" direction while the Y axis is referred to as the "transverse" direction.

The (B) material has a nominal index of refraction (1.64 for example) which is not substantially altered by the stretching process. The (A) material has the property of having the index of refraction altered by the stretching process. For example, a uniaxially stretched sheet of the (A) material will have one index of refraction (1.88 for example) associated with the stretched direction and a different index of refraction (1.64 for example) associated with the transverse direction. By way of definition, the index of refraction associated with an in-plane axis (an axis parallel to the surface of the film) is the effective index of refraction for plane-polarized incident light whose plane of polarization is parallel to that axis.

Thus, after stretching, the multiple layer stack (ABABA...) of material shows a large refractive index difference between layers (1.88 minus 1.64) associated with the stretched direction. While in the transverse direction, the associated indices of refraction between layers are essentially the same (1.64 and 1.64 in the example). These optical characteristics cause the multiple layer laminate to act as a reflecting polarizer that will transmit the polarization component of the incident light which is correctly oriented with respect to the axis 22. Axis 22 is defined as the transmission axis. The light which emerges from the reflective polarizer body 12 is referred to as having a first polarization orientation.

The light which does not pass through the reflective polarizer body 12 has a polarization orientation orthogonal or perpendicular to the first orientation. Light exhibiting this polarization orientation will encounter the index difference

layers in the multilayer stack. In such a configuration, the transmission axis 27 of the dichroic polarizer 11 is preferably aligned with the transmission axis 22 of the reflective polarizer 12. When the dichroic polarizer 11 is on one side of reflective polarizer 12, as shown in FIG. 1, the reflection of light ray 17 on the dichroic polarizer side will be reduced due to attenuation of reflected ray 18 by dichroic polarizer 11 in comparison to the reflection of ray 17 off reflective polarizer 12 without dichroic polarizer 11. The reflectivity of ray 13 off reflective polarizer 12 is not substantially affected by dichroic polarizer 11. This produces an optical polarizer 10 which is antireflective on at least one side. Antireflection of one side of the optical polarizer 10 is useful in displays, particularly in certain backlit displays where the reflected polarization can be used to increase the display brightness while the other side, the viewing side, of the polarizer must not reflect light. Iridescence as seen in transmission through either direction, and iridescence when viewed in reflection from the dichroic polarizer side are reduced by the addition of dichroic polarizer 11. This reduction in iridescence is useful in improving the cosmetic appearance of the display, the extinction ratio of the polarizer, and the optical uniformity of the display.

The configuration of dichroic and reflective polarizers shown in FIG. 1 creates a high efficiency optical polarizer. Combining dichroic polarizer 11 with reflective polarizer 12 results in an optical polarizer 10 which has a higher extinction ratio for transmitted light than that which is achieved using the dichroic polarizer alone. This configuration also produces low reflectivity for ray 17 from the dichroic polarizer side due to attenuation of reflected ray 18 by dichroic polarizer 11. For applications requiring a given extinction ratio and high transmissivity, the increased extinction ratio and low reflectivity of optical polarizer 10 allows the use of a dichroic polarizer 11 which has a lower extinction of the first polarization than could otherwise be used. By lowering the extinction required of dichroic polarizer 11, the absorptive losses in polarizer 11 for transmitted rays 16 and 19 can be reduced. Thus, the optical polarizer 10 has improved transmissive extinction ratios for ray pair 17 and 19 and ray pair 13 and 16, low reflected intensity for reflected ray 18 off of reflective polarizer 12, and lower absorptive losses than could be achieved using a dichroic

excellent extinction in the green and red portion of the spectrum, and less in the blue. This polarizer can be combined with a broad band reflective polarizer in order to provide good extinction at blue wavelengths. Nonuniform optical extinction may also be useful for increasing the optical performance of the combined polarizers. For example, the maximum radiometric transmission from the combination of reflective and dichroic polarizers may be obtained with minimum luminous reflectivity by using a dichroic polarizer with relatively high absorption in the green and less absorption in the blue and red. Insufficient extinction in the reflective polarizer at normal and off-normal angles may also be compensated by increasing the extinction of the dichroic polarizer in the necessary spectral regions. For example, a reflective polarizer that has insufficient extinction for red light of the second polarization at off-normal angles can be compensated by using a dichroic polarizer with relatively red high extinction.

Dichroic polarizer 11 can be incorporated into optical polarizer 10 by placing the reflective and dichroic polarizers in the same optical path or by laminating them together with an adhesive. Dichroic polarizer 11 can be incorporated with reflective polarizer 12 before orientation by extruding or laminating at least one layer of a mixture of dichroic dyestuff in polymer onto the multilayer cast film, by a dichroic dyestuff added to the polymer resin of one or more of the skin layers of the multilayer reflective polarizer, or by adding resin to one or more layers in the multilayer stack. Multilayer extrusion techniques also allow the ability to tailor the distribution of dichroic dye within the individual layers making up the optical stack. This may allow the dye to be located in regions of greatest utility. For example, a dye may be preferably concentrated in regions of maximum or minimum "E" field intensity within the optical stack. By appropriate choice of the dichroic dyestuff and polymer matrix, stretching the resulting film will simultaneously produce the dichroic and reflective polarizers in the proper orientation.

Anthraquinone and azo dyes may be used as the dichroic dye, as well as other dichroic dye materials. In some applications the dye does not have to be highly dichroic when oriented. Applications requiring relatively high absorption of both

polymers, polycarbonate polymers, solution based or radiation cured acrylate based adhesive or non-adhesive coatings, polyethylene terephthalate or other polyester based films, or an additional sheet of reflective polarizer film. In cases where the state of polarized light rays entering or exiting the polarizer 10 from the dichroic polarizer side is not critical, birefringent polymers such as biaxially oriented polyethylene terephthalate may be used as the protective layer.

A dichroic polarizer suitable for use in this invention is described in U.S. Patents 4,895,769 and 4,659,523. The polarizers described in these patents may be combined with the reflective polarizer preferably with the polyvinyl alcohol side of the polarizer adhesively bonded to the reflective polarizer. The dichroic polarizer may be made from relatively thin polyvinyl alcohol coatings (i.e., less than 4.5 grams per square meter). Thin coatings will have less absorption of the polarization perpendicular to the stretch direction, yet still have good extinction in first polarization when the high transmission axis is aligned with the high transmission axis of a reflective polarizer. Thin coatings are also faster to process.

Other optical films may be attached to or used in the optical path of the polarizer 10 for particular applications. Examples of these optical films include circular or elliptical diffusers that either preserve or randomize polarization, hardcoated films, antireflective films, textured antiglare films, compensation films or structures (used for example in liquid crystal displays), and optical retarders commonly used to convert linear to elliptically or circularly polarized light.

The preferred "A" layer of the multilayer reflective polarizer is a crystalline naphthalene dicarboxilic acid polyester such as polyethylene naphthalate (PEN), and the preferred "B" layer is a copolyester of naphthalene dicarboxilic acid and terephthalic acid (CoPEN). PEN and a 70 part naphthalate/30 part terephthalate copolyester (CoPEN) can be synthesized in standard polyester resin kettles using ethylene glycol as the diol. A satisfactory 204-layered polarizer was made by extruding PEN and CoPEN in a 51-slot feed block and then employing two layer doubling multipliers in series in the extrusion. The multipliers divide the extruded material exiting the feed block into two half-width flow streams, then stack the half-width flow streams on top of each other. Such multipliers are know in the art.

Most liquid crystal module 52 such as those shown in Figs. 3, 4, and 5 generally include a thin layer of liquid crystal material sandwiched between two glass layers. To minimize parallax, the configuration shown in Fig. 6 can be used. There the combined polarizers 11 and 12 are located between the liquid crystal 56 and glass layers 58 and 59 of the liquid crystal module 52. By locating the combined polarizers in this manner, parallax which may be otherwise introduced in varying degrees depending upon the thickness of the glass layers is eliminated.

Example 1

A Polaroid Corporation model number HN-38 dichroic polarizing film was placed against the multilayer reflective polarizer formed as discussed above. The polarizers were aligned for maximum transmission of one polarization. The combination of the dichroic and reflective polarizers eliminated visible iridescence of the reflective polarizing film when viewed in transmission in either direction. The dichroic polarizer also eliminated reflected visible iridescence from the reflective polarizer when viewed through the dichroic polarizer. This example shows that the combination of a dichroic polarizer with a reflective polarizer improves the cosmetic uniformity of the reflective polarizer.

Example 2

The reflectivity and transmissivity of the optical polarizer of Example 1 was measured with a Lambda 9 spectrophotometer at 550 nm using a sample beam polarized with a Melles-Griot dichroic polarizer model number 03-FPG-009. Reflectivity measurements were made using an integrating sphere. Separate reflectivity measurements were made with the samples backed first with a white diffuse reflector and then with a black backing. The transmissivity of the combined polarizers was 65.64% when aligned in the spectrophotometer for maximum transmission, and 0.05% when aligned for minimum transmission. When the dichroic polarizer was facing the integrating sphere and an absorbing backing was used, the reflectivity of the combined polarizers was 13.26% when aligned for maximum reflectivity and 4.37% when aligned for minimum reflectivity. The maximum and

Optical Behavior of Multilayer Stacks

The optical behavior of a multilayer stack such as that shown above will now be described in more general terms. The multilayer stack can include hundreds or thousands of layers, and each layer can be made from any of a number of different materials. The characteristics which determine the choice of materials for a particular stack depend upon the desired optical performance of the stack.

The stack can contain as many materials as there are layers in the stack. For ease of manufacture, preferred optical thin film stacks contain only a few different materials. For purposes of illustration, the present discussion will describe multilayer stacks including two materials.

The boundaries between the materials, or chemically identical materials with different physical properties, can be abrupt or gradual. Except for some simple cases with analytical solutions, analysis of the latter type of stratified media with continuously varying index is usually treated as a much larger number of thinner uniform layers having abrupt boundaries but with only a small change in properties between adjacent layers.

The reflectance behavior at any angle of incidence, from any azimuthal direction, is determined by the indices of refraction in each film layer of the film stack. If we assume that all layers in the film stack receive the same process conditions, then we need only look at a single interface of a two component stack to understand the behavior of the entire stack as a function of angle.

For simplicity of discussion, therefore, the optical behavior of a single interface will be described. It shall be understood, however, that an actual multilayer stack according to the principles described herein could be made of hundreds or thousands of layers. To describe the optical behavior of a single interface, such as the one shown in Fig.7, the reflectivity as a function of angle of incidence for s and p polarized light for a plane of incidence including the z-axis and one in-plane optic axis will be plotted.

1) $$r_{pp} = \frac{n2z * n2o \sqrt{(n1z2 - no2sin2\theta)} - n1z * n1o \sqrt{(n2z2 - no2sin2\theta)}}{n2z * n2o \sqrt{(n1z2 - no2sin2\theta)} + n1z * n1o \sqrt{(n2z2 - no2sin2\theta)}}$$

2) $$r_{ss} = \frac{\sqrt{(n1o2 - no2sin2\theta)} - \sqrt{(n2o2 - no2sin2\theta)}}{\sqrt{(n1o2 - no2sin2\theta)} + \sqrt{(n2o2 - no2sin2\theta)}}$$

where θ is measured in the isotropic medium.

In a uniaxial birefringent system, n1x = n1y = n1o, and n2x = n2y = n2o.

For a biaxial birefringent system, equations 1 and 2 are valid only for light with its plane of polarization parallel to the x-z or y-z planes, as defined in Fig. 7. So, for a biaxial system, for light incident in the x-z plane, n1o = n1x and n2o = n2x in equation 1 (for p-polarized light), and n1o = n1y and n2o = n2y in equation 2 (for s-polarized light). For light incident in the y-z plane, n1o = n1y and n2o = n2y in equation 1 (for p-polarized light), and n1o = n1x and n2o = n2x in equation 2 (for s-polarized light).

Equations 1 and 2 show that reflectivity depends upon the indices of refraction in the x, y and z directions of each material in the stack. In an isotropic material, all three indices are equal, thus nx = ny = nz. The relationship between nx, ny and nz determine the optical characteristics of the material. Different relationships between the three indices lead to three general categories of materials: isotropic, uniaxially birefringent, and biaxially birefringent.

A uniaxially birefringent material is defined as one in which the index of refraction in one direction is different from the indices in the other two directions. For purposes of the present discussion, the convention for describing uniaxial birefringent systems is for the condition nx = ny ≠ nz. The x and y axes are defined as the in-plane axes and the respective indices, nx and ny, will be referred to as the in-plane indices.

only examine equation 1. For purposes of illustration, some specific, although generic, values for the film indices will be assigned. Let n1x = n1y = 1.75, n1z = variable, n2x = n2y = 1.50, and n2z = variable. In order to illustrate various possible Brewster angles in this system, no = 1.60 for the surrounding isotropic media.

Fig. 8 shows reflectivity versus angle curves for p-polarized light incident from the isotropic medium to the birefringent layers, for cases where n1z is numerically greater than or equal to n2z (n1z ≥ n2z). The curves shown in Fig. 8 are for the following z-index values: a) n1z =1.75, n2z = 1.50; b) n1z = 1.75, n2z = 1.57; c) n1z = 1.70, n2z = 1.60; d) n1z = 1.65, n2z = 1.60; e) n1z = 1.61, n2z = 1.60; and f) n1z = 1.60 = n2z. As n1z approaches n2z, the Brewster angle, the angle at which reflectivity goes to zero, increases. Curves a-e are strongly angular dependent. However, when n1z = n2z (curve f), there is no angular dependence to reflectivity. In other words, the reflectivity for curve f is constant for all angles of incidence. At that point, equation 1 reduces to the angular independent form: (n2o - n1o)/(n2o + n1o). When n1z = n2z, there is no Brewster effect and there is constant reflectivity for all angles of incidence.

Fig. 9 shows reflectivity versus angle of incidence curves for cases where n1z is numerically less than or equal to n2z. Light is incident from isotropic medium to the birefringent layers. For these cases, the reflectivity monotonically increases with angle of incidence. This is the behavior that would be observed for s-polarized light. Curve a in Fig. 9 shows the single case for s polarized light. Curves b-e show cases for p polarized light for various values of nz, in the following order: b) n1z =1.50, n2z = 1.60; c) n1z = 1.55, n2z = 1.60; d) n1z =1.59, n2z = 1.60; and e) n1z = 1.60 = n2z. Again, when n1z = n2z (curve e), there is no Brewster effect, and there is constant reflectivity for all angles of incidence.

Fig. 10 shows the same cases as Fig. 8 and 9 but for an incident medium of index no =1.0 (air). The curves in Fig. 10 are plotted for p polarized light at a single interface of a positive uniaxial material of indices n2x = n2y = 1.50,

Both Figs. 11 and 12 are valid for the limiting cases where one of the two films is isotropic. The two cases are where material one is isotropic and material two has positive birefringence, or material two is isotropic and material one has negative birefringence. The point at which there is no Brewster effect is where the z-axis index of the birefringent material equals the index of the isotropic film.

Another case is where both films are of the same type, i.e., both negative or both positive birefringent. Fig. 13 shows the case where both films have negative birefringence. However, it shall be understood that the case of two positive birefringent layers is analogous to the case of two negative birefringent layers shown in Fig. 13. As before, the Brewster minimum is eliminated only if one z-axis index equals or crosses that of the other film.

Yet another case occurs where the in-plane indices of the two materials are equal, but the z-axis indices differ. In this case, which is a subset of all three cases shown in Figs. 11-13, no reflection occurs for s polarized light at any angle, and the reflectivity for p polarized light increases monotonically with increasing angle of incidence. This type of article has increasing reflectivity for p-polarized light as angle of incidence increases, and is transparent to s-polarized light. This article can be referred to, then, as a "p-polarizer".

Those of skill in the art will readily recognize that the above described principles describing the behavior of uniaxially birefringent systems can be applied to create the desired optical effects for a wide variety of circumstances. The indices of refraction of the layers in the multilayer stack can be manipulated and tailored to produce devices having the desired optical properties. Many negative and positive uniaxial birefringent systems can be created with a variety of in-plane and z-axis indices, and many useful devices can be designed and fabricated using the principles described here.

In most applications, the ideal reflecting polarizer has high reflectance along one axis and zero reflectance along the other, at all angles of incidence. If some reflectivity occurs along the transmission axis, and if it is different for various wavelengths, the efficiency of the polarizer is reduced, and color is introduced into the transmitted light. Both effects are undesirable. This is caused by a large z-index mismatch, even if the in-plane y indices are matched. The resulting system thus has large reflectivity for p, and is highly transparent to s polarized light. This case was referred to above in the analysis of the mirror cases as a "p polarizer".

Fig. 14 shows the reflectivity (plotted as -Log[1-R]) at 75° for p polarized light with its plane of incidence in the non-stretch direction, for an 800 layer stack of PEN/coPEN. The reflectivity is plotted as function of wavelength across the visible spectrum (400 - 700 nm). The relevant indices for curve a at 550 nm are n1y = 1.64, n1z = 1.52, n2y = 1.64 and n2z = 1.63. The model stack design is a simple linear thickness grade for quarterwave pairs, where each pair is 0.3% thicker than the previous pair. All layers were assigned a random thickness error with a gaussian distribution and a 5% standard deviation.

Curve a shows high off-axis reflectivity across the visible spectrum along the transmission axis (the y-axis) and that different wavelengths experience different levels of reflectivity. Since the spectrum is sensitive to layer thickness errors and spatial nonuniformities, such as film caliper, this gives a biaxial birefringent system with a very nonuniform and "colorful" appearance. Although a high degree of color may be desirable for certain applications, it is desirable to control the degree of off-axis color, and minimize it for those applications requiring a uniform, low color appearance, such as LCD displays or other types of displays.

If the film stack were designed to provide the same reflectivity for all visible wavelengths, a uniform, neutral gray reflection would result. However, this would require almost perfect thickness contorl. Instead, off-axis reflectivity,

The computed off-axis reflectance of an 800 layer stack of films at 75° angle of incidence with the conditions of curve a in Fig. 16 is plotted as curve b in Fig. 14. Comparison of curve b with curve a in Fig. 14 shows that there is far less off-axis reflectivity, and therefore lower perceived color, for the conditions plotted in curve b. The relevant indices for curve b at 550 nm are n1y = 1.64, n1z = 1.56, n2y = 1.65 and n2z = 1.60.

Fig. 17 shows a contour plot of equation 1 which summarizes the off axis reflectivity discussed in relation to Fig. 7 for p-polarized light. The four independent indices involved in the non-stretch direction have been reduced to two index mismatches, Δnz and Δny. The plot is an average of 6 plots at various angles of incidence from 0° to 75° in 15 degree increments. The reflectivity ranges from 0.4 x 10-4 for contour a, to 4.0 x 10-4 for contour j, in constant increments of 0.4 x 10 -4. The plots indicate how high reflectivity caused by an index mismatch along one optic axis can be offset by a mismatch along the other axis.

Thus, by reducing the z-index mismatch between layers of a biaxial birefringent systems, and/or by introducing a y-index mismatch to produce a Brewster effect, off-axis reflectivity, and therefore off-axis color, are minimized along the transmission axis of a multilayer reflecting polarizer.

It should also be noted that narrow band polarizers operating over a narrow wavelength range can also be designed using the principles described herein. These can be made to produce polarizers in the red, green, blue, cyan, magenta, or yellow bands, for example.

Materials Selection and Processing

With the above-described design considerations established, one of ordinary skill will readily appreciate that a wide variety of materials can be used to form multilayer mirrors or polarizers according to the invention when processed under conditions selected to yield the desired refractive index relationships. In general, all that is required is that one of the materials have a different index of refraction in a selected direction compared to the second

cyclohexane dimethanol diol); (f) alkane dicarboxylic acids; and/or (g) cycloalkane dicarboxylic acids (e.g., cyclohexane dicarboxylic acid)), copolymers of polyalkylene terephthalates (e.g., copolymers of terephthalic acid, or esters thereof, with (a) naphthalene dicarboxylic acid, or esters thereof; (b) isophthalic acid, or esters thereof; (c) phthalic acid, or esters thereof; (d) alkane glycols; (e) cycloalkane glycols (e.g., cyclohexane dimethanol diol); (f) alkane dicarboxylic acids; and/or (g) cycloalkane dicarboxylic acids (e.g., cyclohexane dicarboxylic acid)), and styrene copolymers (e.g., styrene-butadiene copolymers and styrene-acrylonitrile copolymers), 4, 4' bibenzoic acid and ethylene glycol. In addition, each individual layer may include blends of two or more of the above-described polymers or copolymers (e.g., blends of SPS and atactic polystyrene).

Particularly preferred combinations of layers in the case of polarizers include PEN/co-PEN, polyethylene terephthalate (PET)/co-PEN, PEN/SPS, PET/SPS, PEN/Eastair, and PET/Eastair, where "co-PEN" refers to a copolymer or blend based upon naphthalene dicarboxylic acid (as described above) and Eastair is polycyclohexanedimethylene terephthalate commercially available from Eastman Chemical Co.

Particularly preferred combinations of layers in the case of mirrors include PET/Ecdel, PEN/Ecdel, PEN/SPS, PEN/THV, PEN/co-PET, and PET/SPS, where "co-PET" refers to a copolymer or blend based upon terephthalic acid (as described above), Ecdel is a thermoplastic polyester commercially available from Eastman Chemical Co., and THV is a fluoropolymer commercially available from 3M Co.

The number of layers in the device is selected to achieve the desired optical properties using the minimum number of layers for reasons of economy. In the case of both polarizers and mirrors, the number of layers is preferably less than 10,000, more preferably less than 5,000, and (even more preferably) less than 2,000.

Suitable multilayer devices may also be prepared using techniques such as spin coating (e.g., as described in Boese et al., J. Polym. Sci.: Part B, 30:1321 (1992)) and vacuum deposition; the latter technique is particularly useful in the case of crystalline polymeric organic and inorganic materials.

The invention will now be described by way of the following examples. In the examples, because optical absorption is negligible, reflection equals 1 minus tranmission (R = 1 - T).

Mirror Examples:

PET:Ecdel, 601 A coextruded film containing 601 layers was made on a sequential flat-film-making line via a coextrusion process. Polyethylene terephthalate (PET) with an Intrinsic Viscosity of 0.6 dl/g (60 wt. % phenol/40 wt. % dichlorobenzene) was delivered by one extruder at a rate of 75 pounds per hour and Ecdel 9966 (a thermoplastic elastomer available from Eastman Chemical) was delivered by another extruder at a rate of 65 pounds per hour. PET was on the skin layers. The feedblock method (such as that described in U.S. Patent 3,801,429) was used to generate 151 layers which was passed through two multipliers producing an extrudate of 601 layers. U.S. Patent 3,565,985 describes examplary coextrusion multipliers. The web was length oriented to a draw ratio of about 3.6 with the web temperature at about 210°F. The film was subsequently preheated to about 235°F in about 50 seconds and drawn in the transverse direction to a draw ratio of about 4.0 at a rate of about 6% per second. The film was then relaxed about 5% of its maximum width in a heat-set oven set at 400°F. The finished film thickness was 2.5 mil.

The cast web produced was rough in texture on the air side, and provided the transmission as shown in Figure 18. The % transmission for p-polarized light at a 60° angle (curve b) is similar the value at normal incidence (curve a) (with a wavelength shift).

another extruder at a rate of 17 pounds per hour. PEN was on the skin layers. The feedblock method was used to generate 57 layers which was passed through two multipliers producing an extrudate of 225 layers. The cast web was 12 mils thick and 12 inches wide. The web was later biaxially oriented using a laboratory stretching device that uses a pantograph to grip a square section of film and simultaneously stretch it in both directions at a uniform rate. A 7.46 cm square of web was loaded into the stretcher at about 100°C and heated to 130°C in 60 seconds. Stretching then commenced at 100%/sec (based on original dimensions) until the sample was stretched to about 3.5 x 3.5. Immediately after the stretching the sample was cooled by blowing room temperature air on it.

Figure 22 shows the optical response of this multilayer film (curve a at normal incidence, curve b at 60 degrees). Note that the % transmission for p-polarized light at a 60° angle is similar to what it is at normal incidence (with some wavelength shift).

PEN:THV 500, 449 A coextruded film containing 449 layers was made by extruding the cast web in one operation and later orienting the film in a laboratory film-stretching apparatus. Polyethylene naphthalate (PEN) with an Intrinsic Viscosity of 0.53 dl/g (60 wt. % phenol/40 wt. % dichlorobenzene) was delivered by one extruder at a rate of 56 pounds per hour and THV 500 (a fluoropolymer available from Minnesota Mining and Manufacturing Company) was delivered by another extruder at a rate of 11 pounds per hour. PEN was on the skin layers and 50% of the PEN was present in the two skin layers. The feedblock method was used to generate 57 layers which was passed through three multipliers producing an extrudate of 449 layers. The cast web was 20 mils thick and 12 inches wide. The web was later biaxially oriented using a laboratory stretching device that uses a pantograph to grip a square section of film and simultaneously stretch it in both directions at a uniform rate. A 7.46 cm square of web was loaded into the stretcher at about 100°C and heated to 140°C in 60

higher for p-polarized light at 60° incidence because the air/PEN interface has a Brewster angle near 60°, so the tranmission at 60° incidence is nearly 100%. Also note the high extinction of s-polarized light in the visible range (400-700nm) shown by curve c.

PEN:CoPEN, 601--High Color A coextruded film containing 601 layers was produced by extruding the web and two days later orienting the film on a different tenter than described in all the other examples. Polyethylene Naphthalate (PEN) with an Intrinsic Viscosity of 0.5 dl/g (60 wt. % phenol/40 wt. % dichlorobenzene) was delivered by one extruder at a rate of 75 pounds per hour and CoPEN (70 mol% 2,6 NDC and 30 mol% DMT) with an IV of 0.55 dl/g (60 wt. % phenol/40 wt. % dichlorobenzene) was delivered by another extruder at a rate of 65 pounds per hour. PEN was on the skin layers. The feedblock method was used to generate 151 layers which was passed through two multipliers producing an extrudate of 601 layers. U.S. Patent 3,565,985 describes similar coextrusion multipliers. All stretching was done in the tenter. The film was preheated to about 280°F in about 20 seconds and drawn in the transverse direction to a draw ratio of about 4.4 at a rate of about 6% per second. The film was then relaxed about 2% of its maximum width in a heat-set oven set at 460°F. The finished film thickness was 1.8 mil.

The transmission of the film is shown in Figure 25. Curve a shows transmission of p-polarized light at normal incidence, curve b shows transmission of p-polarized light at 60° incidence, and curve c shows transmission of s-polarized light at normal incidence. Note the nonuniform transmission of p-polarized light at both normal and 60° incidence. Also note the non-uniform extinction of s-polarized light in the visible range (400-700nm) shown by curve c.

hour. The coPEN was a copolymer of 70 mole % 2,6 naphthalene dicarboxylate methyl ester, 15 % dimethyl isophthalate and 15% dimethyl terephthalate with ethylene glycol. The feedblock method was used to generate 151 layers. The feedblock was designed to produce a gradient distribution of layers with a ration of thickness of the optical layers of 1.22 for the PEN and 1.22 for the coPEN. PEN skin layers were coextruded on the outside of the optical stack with a total thickness of 8% of the coextruded layers. The optical stack was multiplied by two sequential multipliers. The nominal multiplication ratio of the multipliers were 1.2 and 1.22, respectively. The film was subsequently preheated to 310°F in about 40 seconds and drawn in the transverse direction to a draw ratio of about 5.0 at a rate of 6% per second. The finished film thickness was about 2 mils.

Figure 27 shows the transmission for this multilayer film. Curve a shows transmission of p-polarized light at normal incidence, curve b shows transmission of p-polarized light at 60° incidence, and curve c shows transmission of s-polarized light at normal incidence. Note the very high transmission of p-polarized light at both normal and 60° incidence (80-100%). Also note the very high extinction of s-polarized light in the visible range (400-700nm) shown by curve c. Extinction is nearly 100% between 500 and 650nm.

For those examples using the 57 layer feedblock, all layers were designed for only one optical thickness (1/4 of 550nm), but the extrusion equipment introduces deviations in the layer thicknesses throughout the stack resulting in a fairly broadband optical response. For examples made with the 151 layer feedblock, the feedblock is designed to create a distribution of layer thicknesses to cover a portion of the visible spectrum. Asymmetric multipliers were then used to broaden the distribution of layer thicknesses to cover most of the visible spectrum as described in U.S. Patents 5,094,788 and 5,094,793.

Although the present optical polarizer has been described with reference to the preferred embodiment, those skilled in the art will readily appreciate that other embodiments may be utilized and changes made in form and detail without departing from the spirit and scope of the present invention.

9. The optical polarizer of claim 8 wherein the two polymeric materials exhibit no refractive index difference for light of the first polarization, and further which exhibit a refractive index difference for light that does not have the first polarization.

10. The optical polarizer of claim 9 wherein the multilayer stack comprises alternating layers of PEN and coPEN.

11. The optical polarizer of claim 1 wherein the dichroic polarizer is bonded to the reflective polarizer.

12. An optical polarizer, comprising:

a reflective polarizer which transmits light of a first polarization along a first transmission axis, and which reflects light of a different polarization; and

a dichroic polarizer having a second transmission axis substantially aligned with the first transmission axis.

13. The optical polarizer of claim 12 wherein the dichroic polarizer is positioned to provide antireflection on at least one side of the reflective polarizer.

14. The optical polarizer of claim 13 wherein the reflective polarizer is comprised of a multilayer stack that includes at least one birefringent material.

15. The optical polarizer of claim 14 wherein the dichroic polarizer is incorporated into at least one of the layers in the multilayer stack.

16. A display device, comprising:

a reflective-dichroic polarizer, the reflective-dichroic polarizer comprising:

a reflective polarizer which transmits light of a first polarization, and which reflects light of a different polarization; and

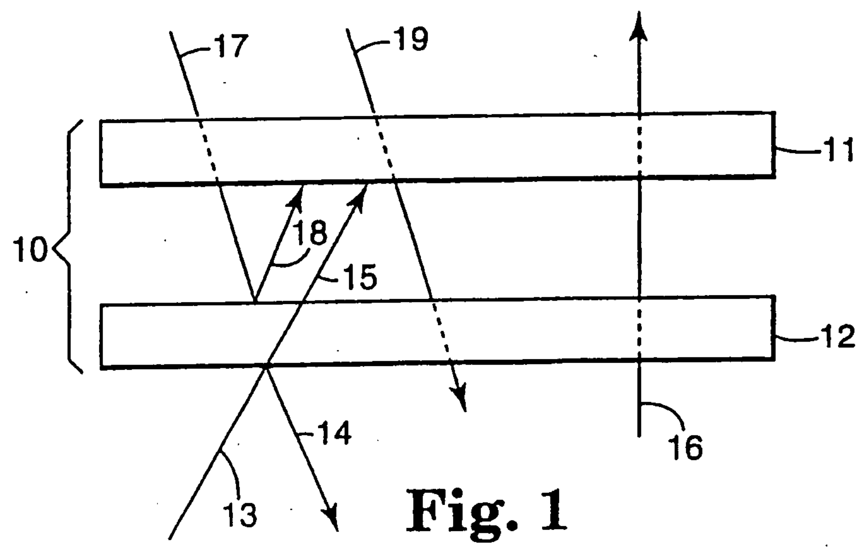


Fig. 1

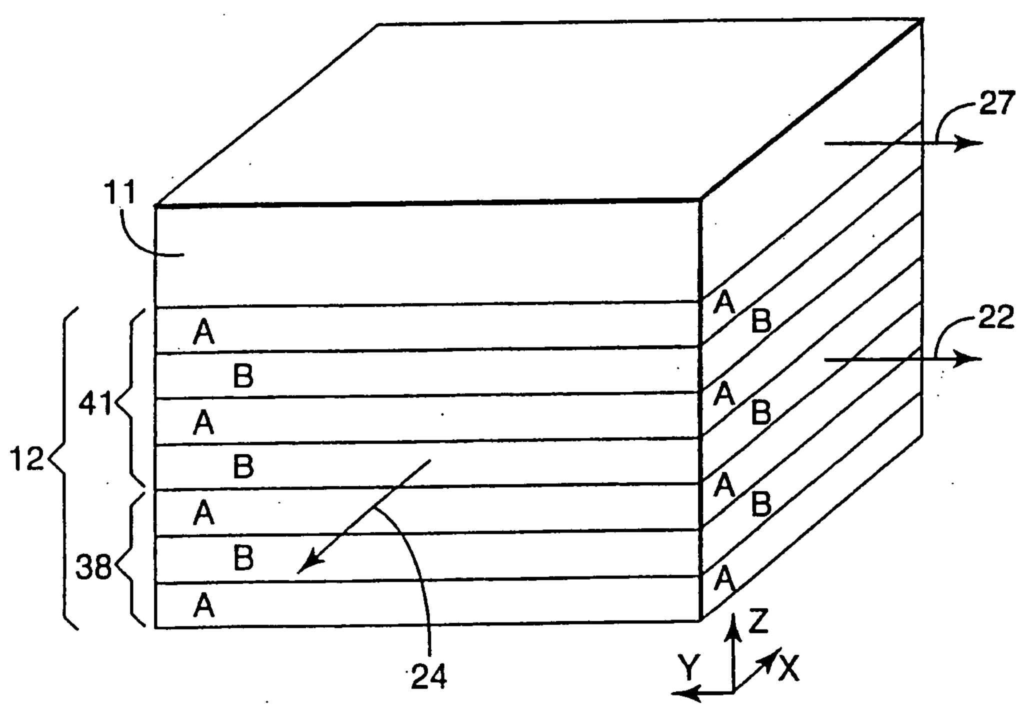


Fig. 2

SUBSTITUTE SHEET (RULE 26)

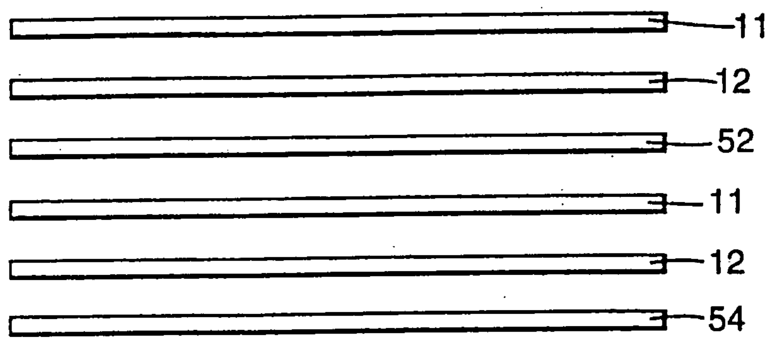


Fig. 5

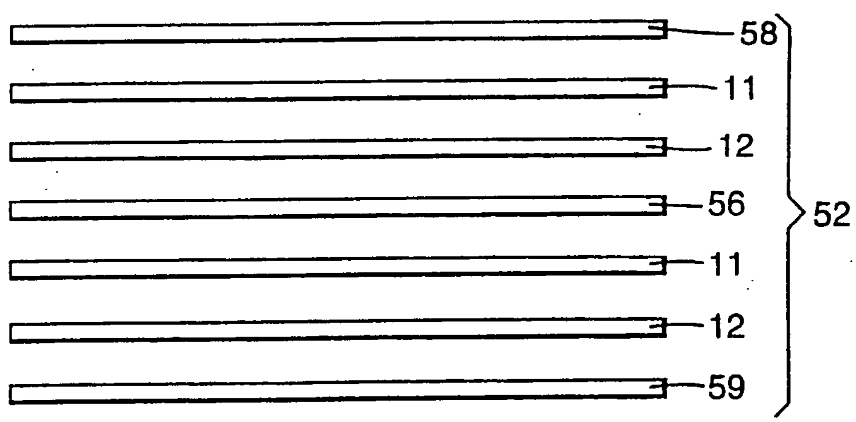
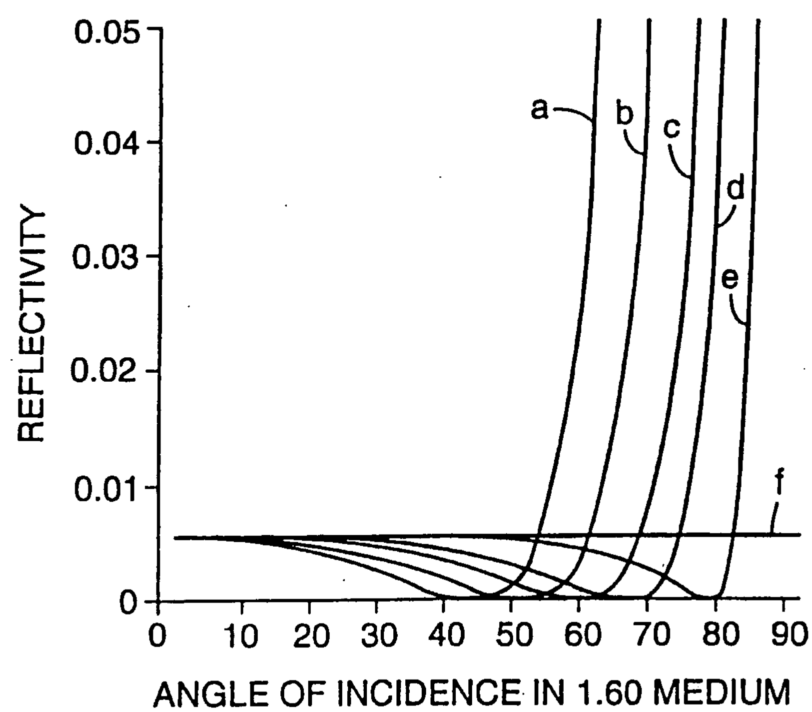


Fig. 6



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0.02
0.01
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b
c
d
e
f
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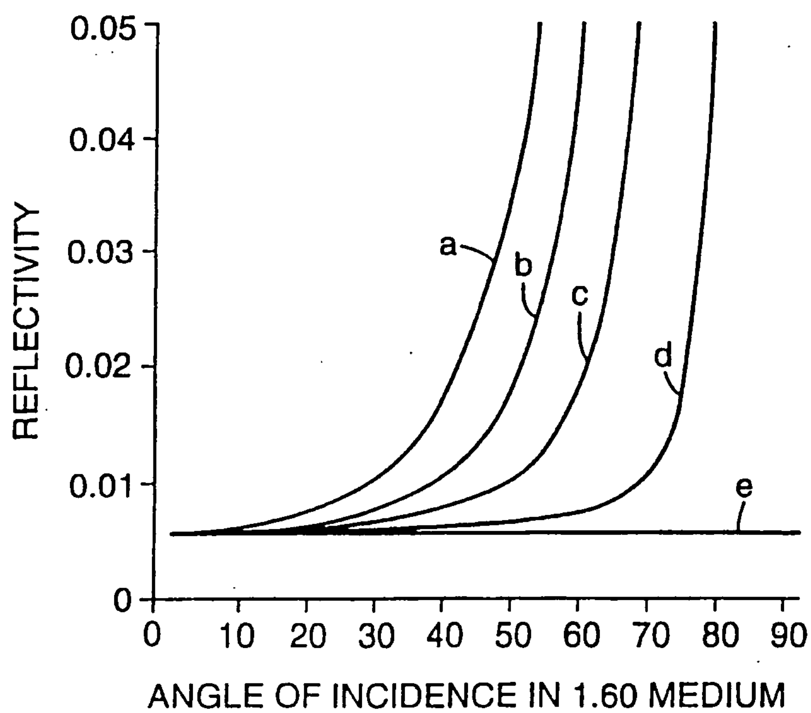
ANGLE OF INCIDENCE IN 1.60 MEDIUM

Fig. 8



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b
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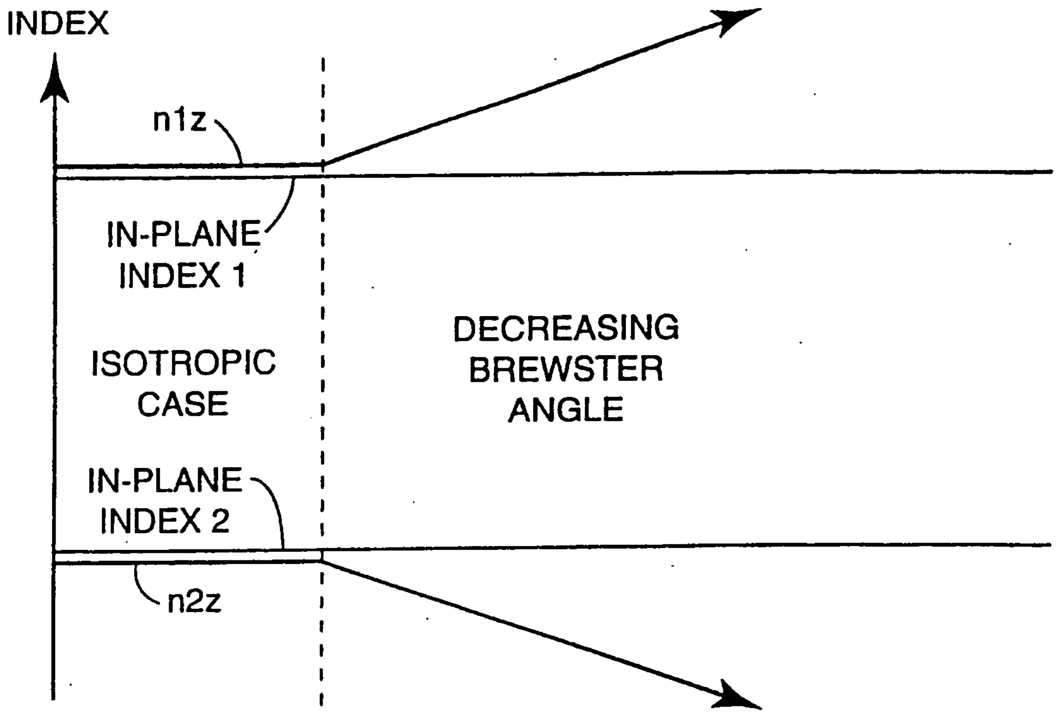
ANGLE OF INCIDENCE IN 1.60 MEDIUM

Fig. 9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BREWSTER
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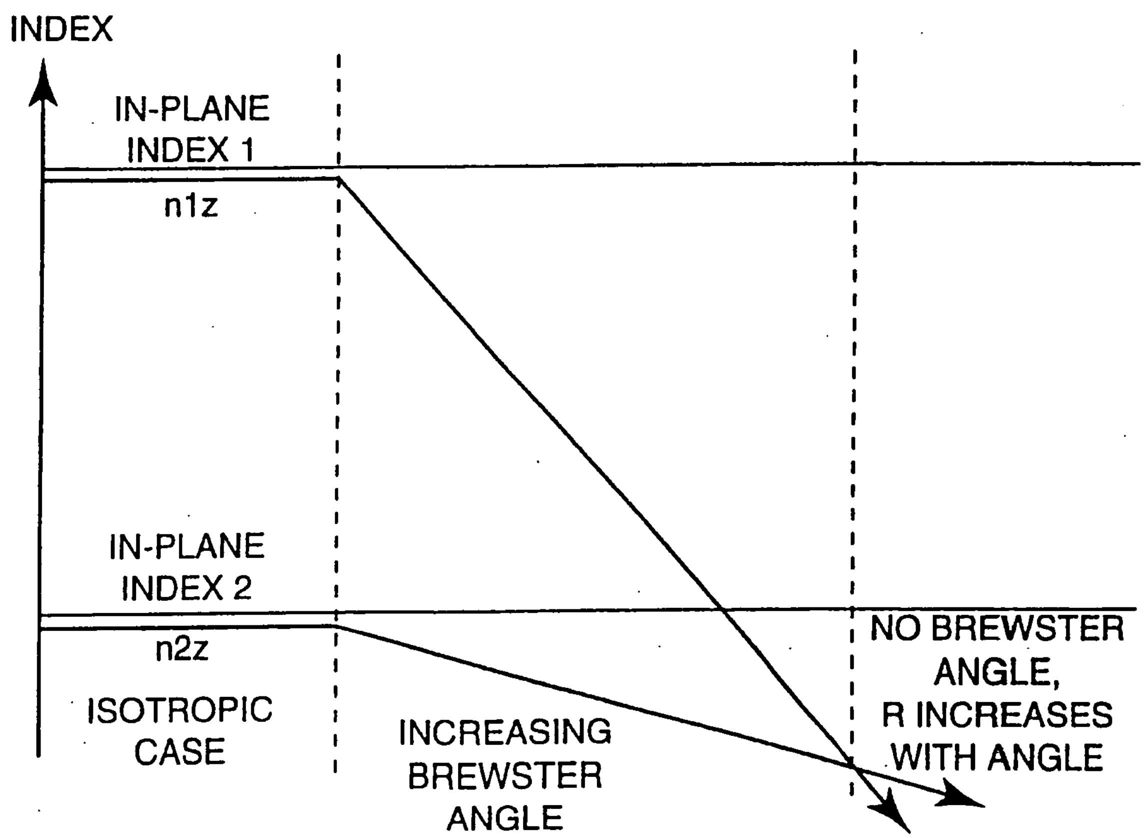
n2z

Fig. 12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IN-PLANE
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ANGLE,
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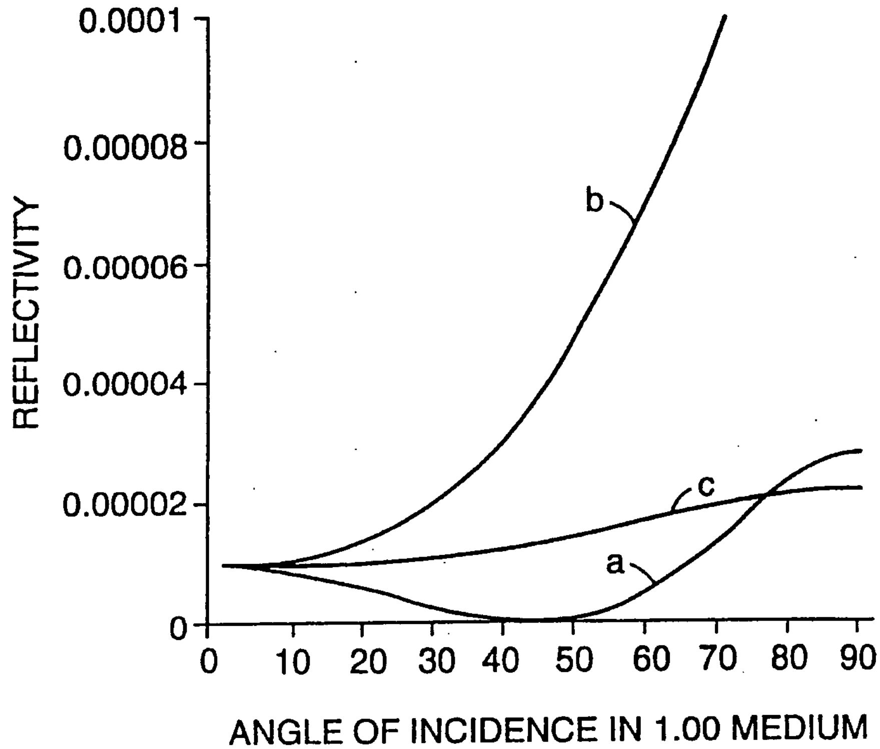
WITH ANGLE

Fig. 13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c
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70
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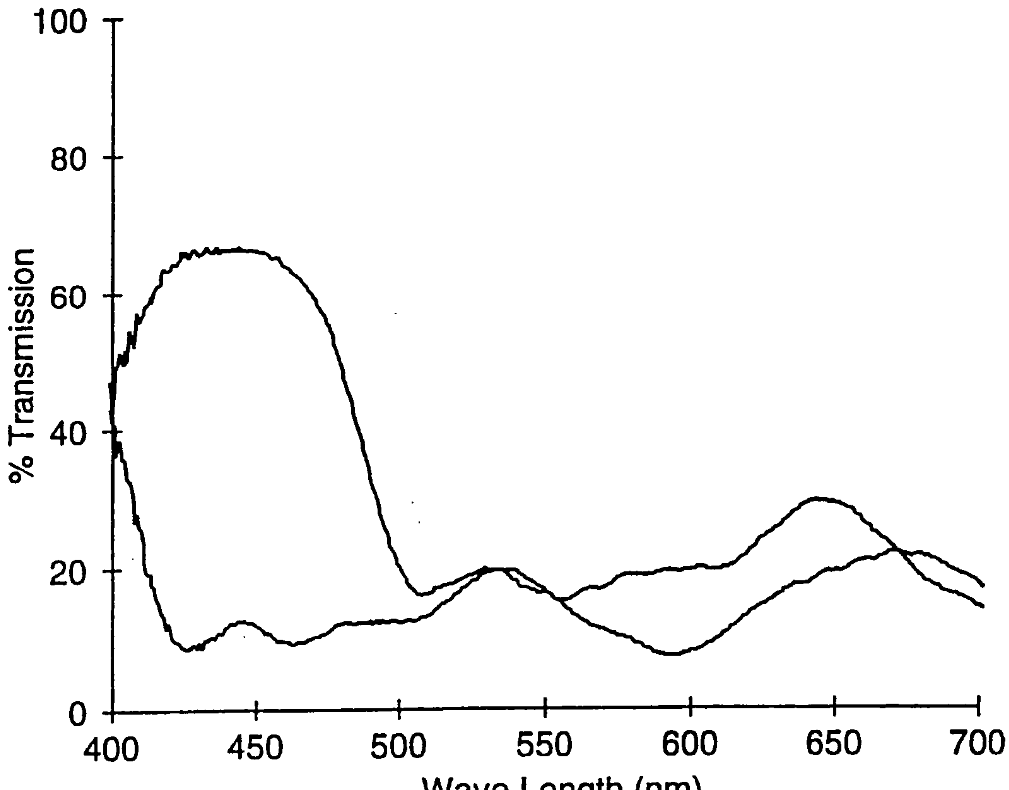
90
ANGLE OF INCIDENCE IN 1.00 MEDIUM

Fig. 16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% Transmission
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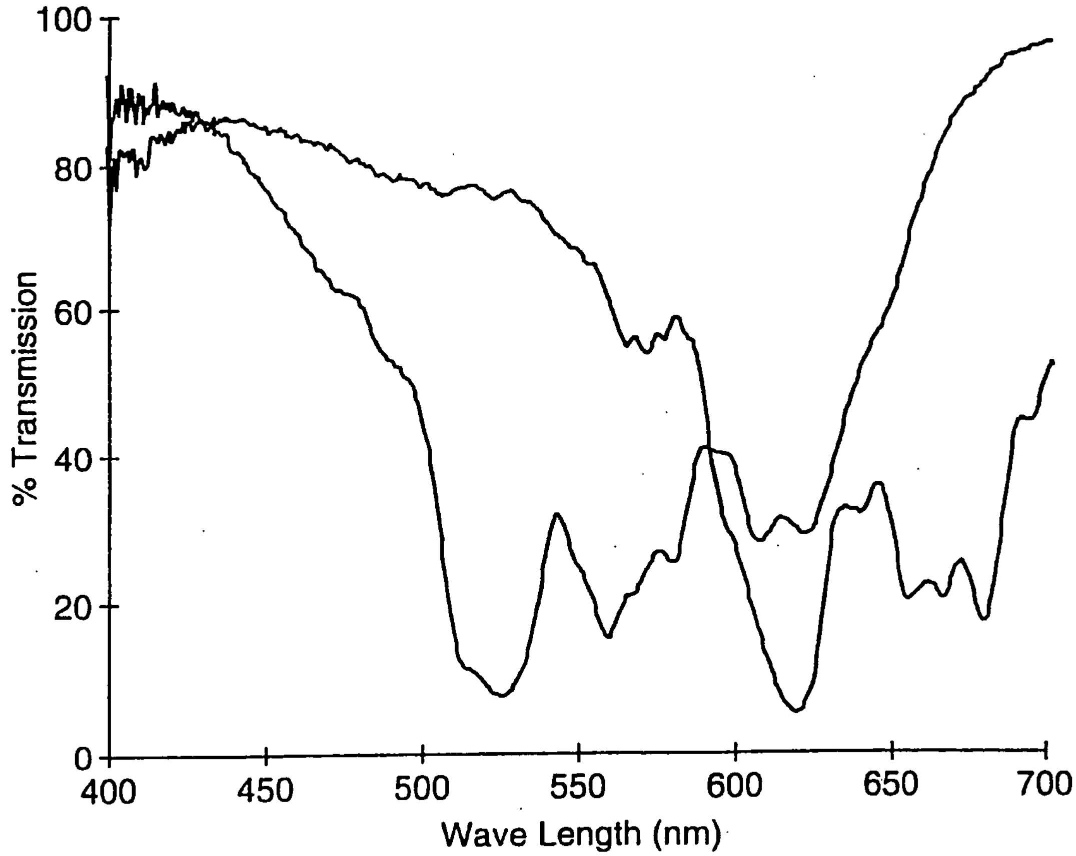
500
550
600
650
700
Wave Length (nm)

Fig. 18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% Transmission
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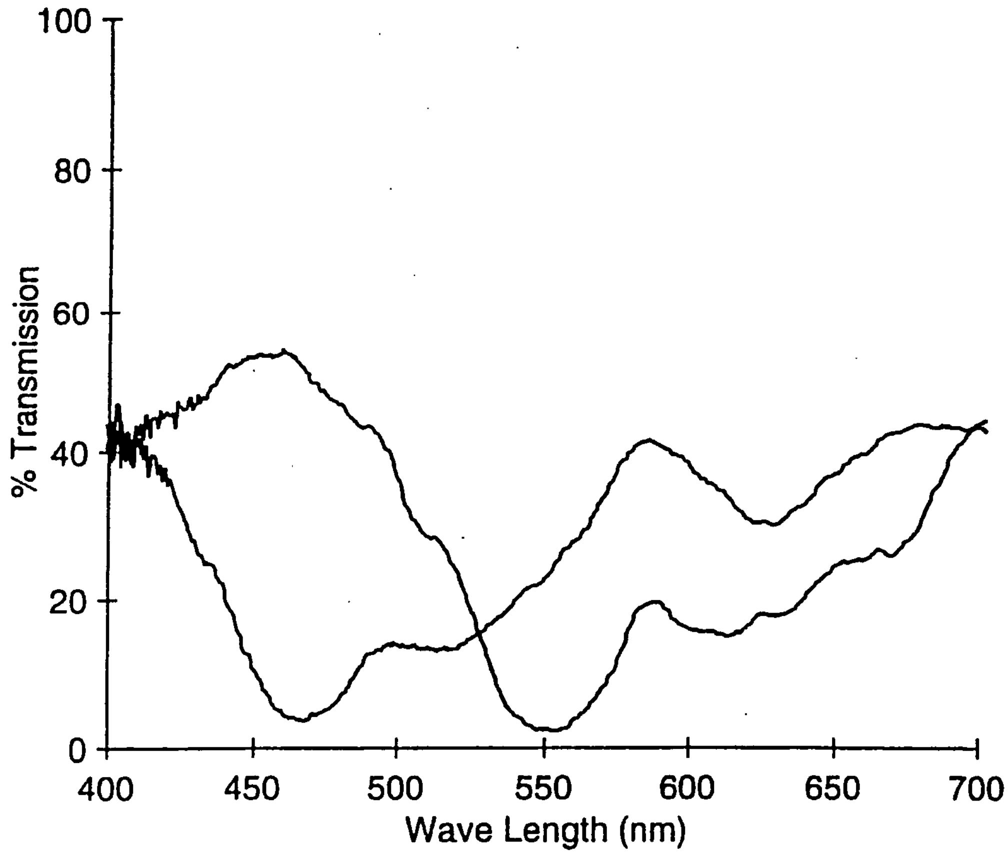
Wave Length (nm)

Fig. 20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% Transmission
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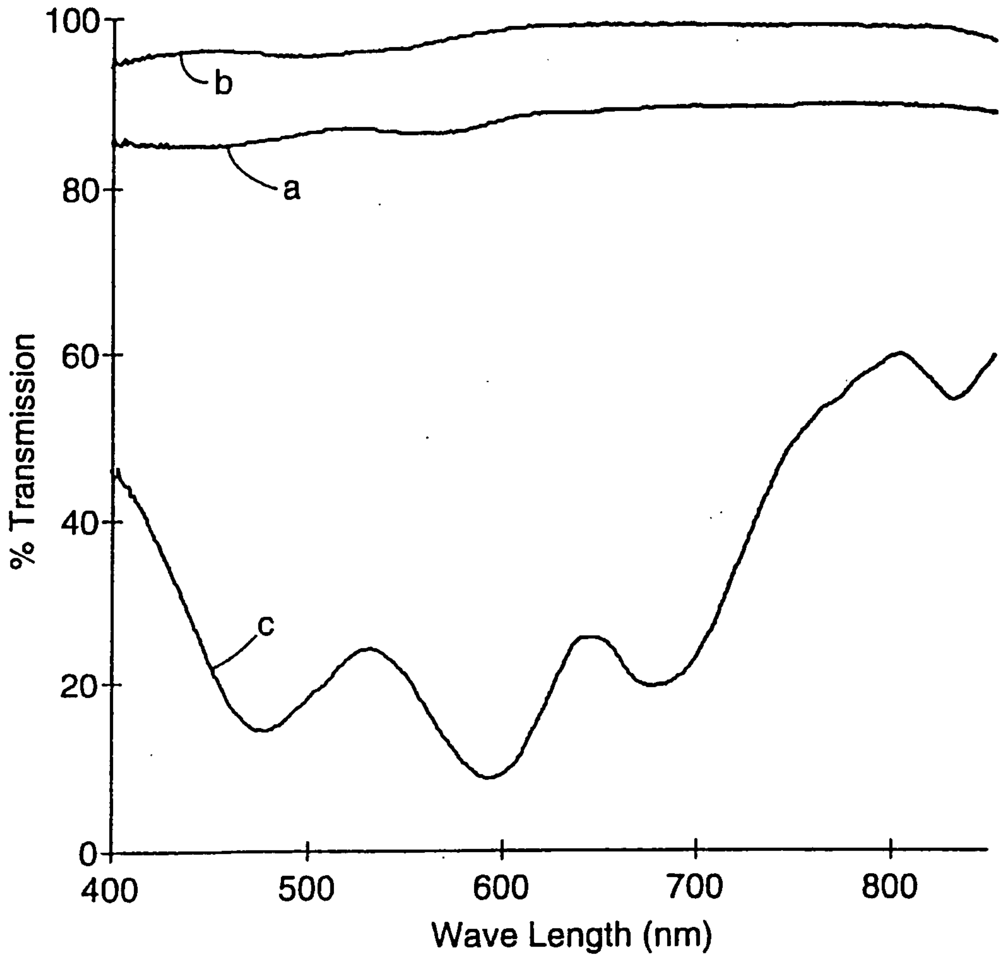
450
500
550
600
650
700
Wave Length (nm)

Fig. 22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% Transmission
b
a
c
400
500
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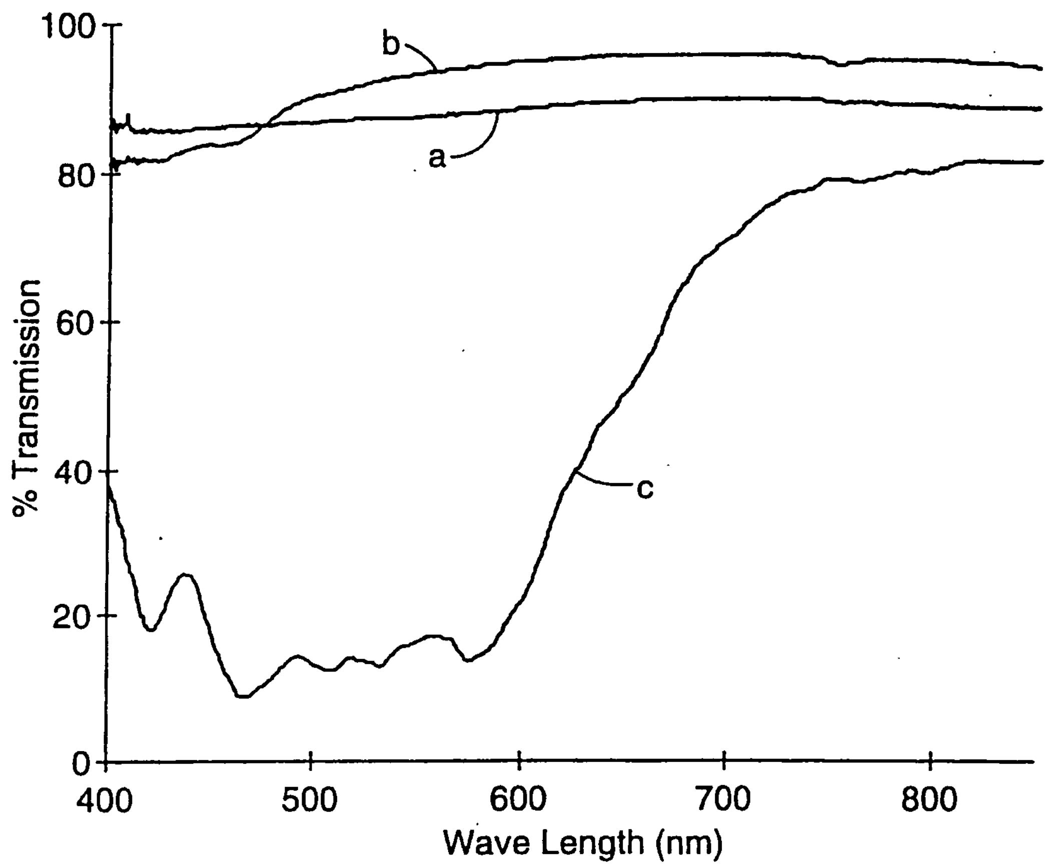
700
800
Wave Length (nm)

Fig. 24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% Transmission
400
500
600
700
800
Wave Length (nm)
a
b
c

Fig. 26

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 94/14324

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B5/30 G02F1/1335

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP,A,4 184 429 (SEIKO EPSON) 1 July 1992	1,2,12, 16,18
A	see abstract; figure 4 ---	4,8,14
X	JP,A,4 141 603 (SEIKO EPSON) 15 May 1992	1,2,12, 16,18
A	see abstract; figure 5 ---	4,6,8,14
X	DE,A,41 21 861 (HITACHI) 16 January 1992 see page 3, line 60 - line 68 see page 4 - page 6 see figure 9 ---	1,2,11, 12,16,18

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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1

Date of the actual completion of the international search	Date of mailing of the international search report
12 April 1995	21.04.95
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Ward, S

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 94/14324

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
JP-A-4184429	01-07-92	NONE		
JP-A-4141603	15-05-92	NONE		
DE-A-4121861	16-01-92	JP-A-	4278903	05-10-92
		KR-B-	9408668	24-09-94
		US-A-	5157526	20-10-92
		JP-A-	4212104	03-08-92
WO-A-9411776	26-05-94	NONE		
EP-A-0573905	15-12-93	JP-A-	6051399	25-02-94
EP-A-0488544	03-06-92	CA-A-	2056153	27-05-92
US-A-3610729	05-10-71	NONE		